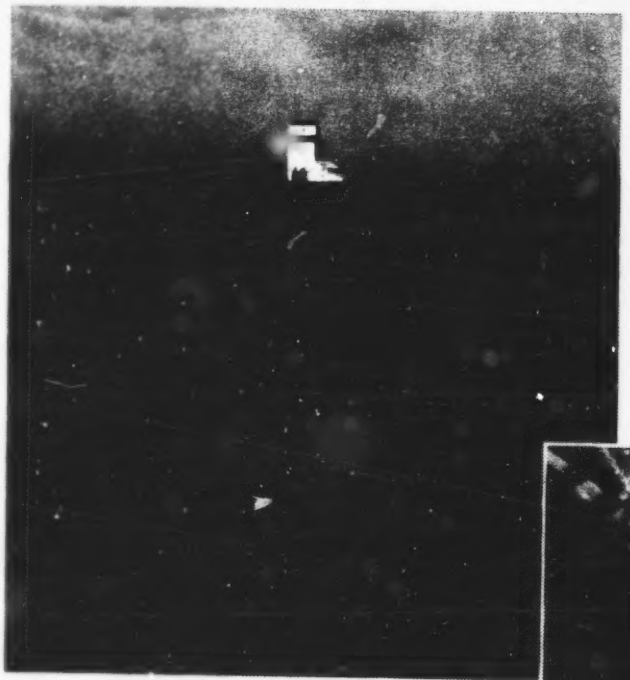
Saskatchewan Agriculture

Agriculture Development Fund

Growing Flax



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FORWARD

The Flax Council of Canada, founded in 1984, has put together, with the help of many researchers, crop scientists, and farmers, this book on flax production and handling, for distribution to flax producers in Western Canada.

This is the first project conducted by the Flax Council of Canada and it came about when Flax Growers Western Canada expressed the desire to have a new, up to date production book printed. It has been many months in the making. The Flax Council co-ordinated numerous papers and information supplied by people in the industry and worked with these people to produce a book that we sincerely hope is helpful to the flax grower in every way. We hope it will also be educational to anyone interested in flax — it purpose, uses, growing conditions, and benefits to Canada.

It is the desire of the Flax Council to distribute this book widely and make it readily available to all producers of flax and to educational facilities.

We sincerely appreciate the tremendous amount of work that so many talented people put into this booklet, and trust that it will be of great value to both the experienced flax grower and to those who are growing this valuable crop for the first time.

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GROWING FLAX IN CANADA

History 1
Description 1
Uses and Markets 2
- Linseed Oil 2
- Linseed Meal 3
- Edible Uses of Linseed Oil and Flaxseed 3
- Flax Straw for Feed 4
- Flax Straw for Fibre 4

Production and Exports 4
Crop Rotation 4
- Brown and Dark Brown Soil Zones 5
- Black and Gray Black Soil Zones 5

Varieties 5
- Early Varieties 5
- Medium-Early Varieties 6
- Late Varieties 6

Seed and Seeding Practices 6
- Choice of Land 6
- Choice of Seed 6
- Seed Damage and Effect on Plant Stand 7
- Seed Treatment 7
- Seedbed Preparation 7
- Method of Seeding 13
- Rate of Seeding 13
- Plant Stand 13
- Seeding Date 13

Fertilizer Practices 14
Insect Pests 14
- Pests of Flax Only 14
- Pest of Flax and Other Crops 14
- Minor Pests of Flax 15

Control of Weeds 15
Diseases 16
- Rust 16
- Fusarium Wilt 16
- Pasmo 17
- Stem Break and Browning 17
- Seedling Blight & Root Rot 17
- Asters Yellows 18
- Crinkle 18
- Minor Diseases 18

Physiological Disorders 18
- Chlorosis and Top Dieback 18
- Heat and Frost Canker 18
- Injury Due to Herbicides 18

Harvesting and Threshing 18
Management of Flax Straw 19
Storage and Cleaning of Seed 20
Storage Insects 20

ILLUSTRATIONS

Figure 1. Flax plant 8
2. Longitudinal section of a flax flower 8
3. Cross section of a flax boll showing 9 of a possible 10 seeds in 5 segments 8
4. Mature flax boll, a) closed and b) semi-dehiscent 8
5. Flax production areas of the prairies 9
6. Seed condition: 9
a) normal
b) cracked
c) split
d) blighted and moldy
e) weathered
f) frozen
7. Flax bollworm (within boll) 10
8. Flax bollworm (outside boll) 10
9. Red-backed cutworm 10
10. Early cutworm 10
11. Bertha armyworm 10
12. Beet webworm moth 10
13. Beet webworm caterpillar 11
14. Tarnished plant bug 11
15. Zebra caterpillar 11
16. Aphids 11
17. Wireworms 11
18. Variegated fritillary - adult 11
19. Variegated fritillary - larvae 11
20. Rust; numerous orange uredia on leaves 12
21. Rust; orange (summerstage) and black (overwintering stage) on flax boll 12
22. Fusarium wilt; dead (brown) and wilting (yellow) plants 12
23. Pasmo; alternating green and brown (infected) bands on the stem 12
24. Stem break and browning; plants often break at the canker that weakens the stem base 12
25. Aster yellow in the field 12
26. Aster yellows; flowers are sterile 12
27. Heat and frost canker; stems at the soil line are girdled 12
28. Heat and frost canker; plants have toppled over 12
29. Straw bunching unit 12

TABLES

1. Percent fatty acid composition of linseed oil and other vegetable oils 3
2. Average flax production in the prairie provinces, 1981-1985 4
3. Distribution of flax on summerfallow and stubble in the prairie provinces, 1980-1984 5
4. Characteristics of commonly grown flax varieties 21
5. Yield of flax varieties in the three soil zones of the prairies - Cooperative Flax Tests, 1983-1985 22
6. Fungicides for treatment of flaxseed 22
7. Plant stand counts and seed yield of Linott averaged for 1971 and 1972 13
8. Yield of flax varieties in five seeding dates at two locations Morden and Portage la Prairie, 1982-1984 22

FLAX FACTS

Flax is a profitable crop to grow because disease-resistant, high yielding varieties are available. Herbicides can be used to control weeds not easily controlled in a cereal crop, and thus the crop fits well into rotations.

A ready export market is well-established. Canada's export trade in flaxseed is reliable, because our seed is higher in oil content and quality than seed from any other country.

For a high yield of seed of good quality:

-use a variety that is resistant to rust and wilt.

-sow clean, sound seed; treat the seed with a recommended fungicide.

-prepare a firm, weed-free seedbed on soil that keeps uniformly moist.

-rotate flax crops to prevent disease build-up; only one year in four should be flax.

-control weeds with proper use of recommended herbicides.

-harvest the crop at the appropriate stage of maturity.

-thresh carefully to avoid cracking the seed.

HISTORY

Flax is associated with the earliest recorded civilization. Bundles of flax fibres and linen that were 10,000 years old, were found amoung the remains of Stone Age people in Switzerland. By the year 3,000 B.C., flax was a well established crop in Mesopotamia and the Nile Valley. Linen was worn in ancient Egypt, the Egyptians used linen cloth to wrap their mummies. Linseed oil was used in embalming, and flax is mentioned in the writings of the Old Testament and of the ancient Greeks and Romans. Fibre flax has been grown from the earliest times in European Russian and Central Asia. Flax and hemp were the two main fibre crops of the Middle Ages, when throughout Europe flax was cultivated for both its fibre and seed oil.

Flax was introduced into North America by the earliest settlers as a fibre crop. While cotton production in the United States severely limited the development of a flax linen industry, the development of linseed oil manufacturing in the beginning of the nineteenth century assured a steady market for North American oilseed flax. The history of flax in Canada dates back more than 300 years. It is generally believed that Hebert, the first farmer in Canada, grew flax in 1617 at the site of the present courthouse in Quebec City. Early records show that in 1720, New France produced 24.8 metric tonnes (27.3 tons) of flaxseed. With time, flax production expanded and moved westward into Ontario, and by 1875, with the opening of virgin land by European settlers, flax was introduced into Western Canada. The ability to yield well on newly-broken land and the absence of weed species that now are present on the Prairies, contributed to the expansion of flax production to a high of 810,000 hectares (2,000,000 acres) by 1912. Production declined through the 1920's and the 1930's because of drought and problems with the wilt disease, and in 1933 reached a low of 16,000 tonnes (17,600 tons) produced on about 100,000 hectares (247,000 acres). As a result, Canada was required to import over 50% of its flaxseed requirement. By the 1940's, varieties with resistance to wilt were generally available, and flax production became more stable as it could be regularly planted on the same land. During World War II, a surplus of wheat and a government support price for flax caused a 10 fold increase in flax production. The war introduced many farmers to flax and it emerged as an alternate cash crop to wheat and other cereals. During the 1960's and 1970's, flax production fluctuated between 240,000 and 1,240,000 tonnes (264,500-1,366,500 tons) due to variable demand for flaxseed. In recent years, production has stabilized at an annual level of 500,000 to 700,000 tonnes (551,000-771,500 tons).

DESCRIPTION

Flax belongs to the genus **Linum**, one of 10 genera in the family Linaceae. The genus contains over 100 annual and perennial species. Cultivated flax belongs to the species, **L. usitatissimum**, and varieties are of two types; one is grown for oil and the other for fibre production. The fibre from fibre flax varieties is used in the manufacture of linen. Fibre varieties have longer straw with fewer branches than oilseed varieties. Fibre flax varieties produce a higher yield of higher quality fibre, but produce a lower seed yield with a lower content of oil than oilseed varieties. There is no commercial production of fibre flax in North America, although in Canada there is renewed interest in its production. While oilseed varieties are grown specifically for the oil extracted from the seed, the straw is a source of fibre for cigarette and fine bond paper. Only oilseed flax will be addressed in this publication.

Flax is an annual plant that grows to a height of 40 to 91 cm (16-36 in.), depending on variety, plant density, soil fertility and available moisture. The plant has one main stem, but two or more branches (tillers) may develop from the base of the plant when plant density is low and soil nitrogen is high (Fig. 1). The main stem and branches give rise to a terminal, multi-branched

inflorescence called a panicle or cyme, which bears the flowers. (Fig. 1) The plant has a short, branched taproot which may extend to a depth of over 1 metre (39 inches), with lateral branches extending approximately 0.3 m (12 in.).

The life cycle of the flax plant consists of a 45 to 60-day vegetative period, a 15 to 25-day flowering period and a maturation period of 30 to 40 days. Water stress, high temperature, and disease can shorten any of these growth periods. Although there is a period of intense flowering, a small number of flowers may continue to appear until maturation. During maturation, under high soil moisture and fertility, stems may remain green and new growth may occur leading to a second period of intense flowering.

Flower opening begins shortly after sunrise on clear, warm days and petals are shed in the early afternoon. The flower parts, petals, sepals and stamens, all occur in units of five. (Fig. 2) Flax varieties can be distinguished by the color of the flower parts. The color of petals can range from dark blue to very light blue, or are white or pale pink. The anthers are a shade of blue or are yellow. The style and filaments that bear the anthers are blue or colorless.

The mature fruit of the flax plant is a dry boll or capsule. Maturation of the boll commences 20 to 25 days after flowering. The boll has five segments which are separated by a wall or septum (Fig. 3). Each segment produces two seeds separated by a low partition called a "false septum", whose margin may be hairy or smooth, depending on the variety. With complete seed set, the boll contains 10 seeds, though an average of six to eight seeds per boll is usual. When ripe, the bolls of Canadian varieties are semi-dehiscent, that is, the boll opens at the apex and the five segments separate slightly along the margin (Fig. 4b). At this stage the bolls can allow the entrance of moisture and weathering of seeds may result. The bolls rarely dehisce so far as to allow the seeds to fall out.

Flax seeds are flat, oval, and are pointed at one end. A thousand seeds weigh from 4.5 to 7.0 grams, depending on variety and growing conditions. Seed of different varieties range in color from light to dark reddish brown or yellow. Mottled seed, a combination of yellow and brown on the same seed, is a physiologic condition, and is not an inherited characteristic. The seed is covered with a mucilaginous coating that imparts a high gloss and causes the seed to become sticky when wet. The presence of mucilage on flaxseed can be detrimental. Since mucilage is hygroscopic, it may swell during periods of prolonged rainfall and high humidity and in effect, glue the mature seeds to the surface of the septa of the boll. This results in a loss of mucilage and a reduction in grade due to the scabby appearance of the weathered seed and a reduced test weight.

Flax is self-pollinated, but from 0.3 to 2% outcrossing may occur under normal circumstances. Insects are the primary agents of outcrossing.

USES AND MARKETS

LINSEED OIL

Flax is grown primarily for the linseed oil contained in the seed. Oil content ranges from 40 to 45%, depending on the variety and growing conditions. Linseed oil is considered a high quality "drying oil" due to its ability to rapidly form a durable film upon exposure to air. The drying property of linseed oil is the result of a high content of the unsaturated fatty acids - oleic, linoleic and linolenic (Table 1). Quality of linseed oil is determined by the percentage of these unsaturated fatty acids, particularly linolenic acid. The linolenic acid content in flax can vary from 45 to 60%, depending on variety and growing conditions. The relative drying quality of linseed oil is expressed as "iodine value" indicating the milligrams of iodine absorbed by a gram of oil. The value indicates the proportion of the different fatty acids that comprises the oil; the greater the proportion of highly unsaturated fatty acids, the better the drying quality. The quality of oil from Canadian flaxseed ranges from 175 to 210 iodine units.

Although varieties inherently differ in oil content and iodine value, these factors are also influenced by the environment under which flaxseed is produced. Cool temperatures during the critical 10 to 25-day period following flowering, favor increased levels of oil and linolenic acid. Consequently, flax grown in cool, long-day northern latitudes has a higher oil content and iodine value than that grown in warmer climates where the days are shorter. Canadian flaxseed is, therefore, of superior oil quantity and quality than flaxseed produced in most other countries.

Because of its unique drying properties linseed oil is used extensively in the manufacture of protective coatings such as paints, stains, lacquers and varnishes. The oil is also used in soaps, putty, linoleum, oilcloth, printing ink, patent leather, and as a core oil in making sand forms for metal casting. Linseed oil has found some use as an anti-spalling and curing agent for concrete surfaces including those of highways and bridges.

Traditionally, flax has been the primary source of oil for the manufacture of protective coatings. However, since about 1950 the use of

linseed oil has declined especially in North America. New technology has allowed soybean oil and other oils to be used as substitutes for linseed oil in drying products. Linseed oil is a superior drying oil and is preferred over soybean oil but only if the price is competitive. Fluctuating supplies of flaxseed have caused linseed oil to be priced occasionally at an uncompetitive level compared to soybean. The development of non-oil containing latex paints has also contributed to the decline in the use of linseed oil. Latex paints have proved popular because of the convenience of application and clean-up. However, linseed paints have a decided advantage over latex paints for exterior painting and this market has remained strong.

TABLE 1
Percent fatty acid composition of linseed oil and other vegetable oils

Fatty Acid	Linseed	Soybean	Sunflower	Corn	Canola
Palmitic	7.0	11.5	7.2	12.1	3.5
Stearic	4.0	3.9	4.1	2.3	1.5
Oleic*	20.0	24.6	16.2	28.7	60.0
Linoleic*	17.0	52.0	72.5	56.2	20.0
Linolenic*	52.0	8.0	0.0	0.7	10.0

*Unsaturated fatty acids

LINSEED MEAL

The meal fraction of crushed flaxseed contains from 34 to 42% protein, 85% of which is digestible. Linseed meal, or oil cake, can be produced by the hydrolic or expeller process, or by solvent extraction. Meal produced by either method has the same nutritional value except for fat content. Meal from the expeller method contains 5.7% fat whereas the solvent meal contains 2.9% or less.

Linseed meal is used as a protein supplement in feed primarily for livestock. The meal is high in crude fibre but is deficient in the essential amino acid lysine. It is, therefore, limited as the sole source of protein in a protein supplement and is often combined with grains and other feed in the manufacture of mixed feeds. The unique feature of linseed meal, and the characteristic that made it so popular as a livestock feed, is its ability to act in a gentle regulating way upon the digestive system. A small amount of linseed meal is often included in rations as insurance against animals going off feed. The "regulating" action and the excellent palatability of linseed meal is attributed to a mucilage content that runs as high as 10%. In addition to improving digestion in livestock, linseed mucilage is further reported to be responsible for the removal of toxic metabolites produced during digestion, improved hair luster and reduction of the occurance of bloat. Some of these properties are attributed to the ability of the meal to absorb and retain as much as eight times its weight in water. This is more than double the capacity of soybean meal and has made linseed meal a popular ingredient in milk replacer formulae for dairy cattle in Europe.

The presence of a vitamin B_6 antagonist in linseed meal limits its use in poultry feeds to low proportions or to feeds supplemented with pyridoxine. The use of linseed meal in swine feeds is also limited.

EDIBLE USES OF LINSEED OIL AND FLAXSEED

Use of flax in products for human consumption is limited. Linseed oil is used as an edible oil in some countries but not in Canada. The high linolenic acid content in linseed oil, which causes a disagreeable odor, rapid oxidation and rancidity, discourages its use in the edible market. Research is being carried out in Canada and Australia to develop an edible linseed oil by reducing the linolenic acid content to less than 5%.

Small quantities of whole flaxseed are considered beneficial in the human diet primarily as an aid to digestion due to its high mucilage and fibre content. It is found in Canadian markets in specialty products such as bread, and cooked or dry cereals.

Flaxseed, brown or yellow, is a small volume product in the health food industry. In North America, the market for yellow-seeded or "golden" flax is limited to organic health food products. Most of the yellow-seeded flax grown under contract in Canada is exported to the European Economic Community and used primarily as a topping product in the food industry. Yellow flaxseed, generally cleaned to 99.5% purity, commands a premium price over brown flaxseed because of its attractive visual characteristics in specialty markets.

Flaxseed contains the natural toxicants, linamarin and linatine, which may be hazardous if a large enough quantity of flaxseed is consumed. Linamarin, a cyanogenic glucoside, will break down to release small amounts of highly toxic hydrogen cyanide when the seed is crushed and placed in water. Linatine is an antagonist of vitamin B_6.

Flaxseed is a potent allergen to some individuals. Green or frost-damaged seed may contain prussic acid, and therefore, should be

avoided. For edible purposes, only high quality flaxseed should be used. Up to 12% flaxseed in food products is considered safe by the Canadian Food and Drug Administration.

FEEDING VALUE OF FLAX STRAW

Mature flax straw of good quality can be fed to livestock. Feeding of flax straw to livestock has increased recently, particularly in the drier areas of Western Canada where a need has arisen for roughage diets of relatively low cost.

Flax straw intended for use as feed should be tested to determine its nutrient levels and digestability, as well as the amount of prussic acid and nitrates that may be present. Protein content of the flax straw is low and varies between 3-5%. The fibre content is high.

Cattle feeding trials in 1986 have indicated that flax straw combined with barley gave a good return when cost per pound of gain was considered. A ration of flax straw and barley was economical when the cost of hay was $75/tonne or higher. It is evident that flax straw can be used as a roughage in cattle rations.

Caution: Green flax straw should not be fed or grazed as it is high in prussic acid. The danger of prussic acid poisoning is much higher if the immature flax is frozen. Use only mature flax straw as a cattle feed.

FLAX STRAW AS A SOURCE OF FIBRE

Flax straw can provide a source of additional income for flax growers. Mature, weed-free straw is purchased by paper companies, processed to remove the shives and the tow (raw fibre) is shipped to paper mills. On the average, 1 tonne of straw is produced per hectare (.45 ton/acre), and 3 tonnes (3.3 tons) of straw are required to produce 1 tonne (1.1 ton) of paper stock. The paper is used primarily for production of cigarette and fine bond paper.

Tow from oilseed flax has been used to some extent in upholstery of furniture. Fibre from oilseed flax is short and for this reason has had limited used in the textile industry. However, new processing technology may allow greater use of short fibre for the production of linen. There is increasing demand for linen in the textile industry, both in North America and European countries. Linen is superior to other natural fibres in strength and absorbency, and is increasing in popularity, especially for blending with natural fibre and synthetics.

PRODUCTION AND EXPORTS

PRODUCTION

Annual flax production in Canada in the 5-year period of 1981-1985 ranged from 444,000 to 904,500 metric tonnes (489,300-996,800 tons) grown on 431,000 to 740,000 hectares (1,065,00-1,828,500 acres). Flax is grown mainly in the Prairie provinces, but some flax is grown in Ontario and Quebec. In 1981-1985, Manitoba, Saskatchewan and Alberta accounted for 61, 32 and 7%, respectively, of the total flax production in Canada (Table 2). Flax is grown in almost all of the agricultural areas of the prairies (Fig 5). The greatest concentration of flax production is in southern Manitoba.

Table 2: Average flax production in the prairie provinces, 1981-1985.

Area Province	Production (hectares*)	Yield (metric tonnes*)	(kg/ha*)
Canada	596,500	648,000	1085
Manitoba	360,000	395,000	1095
Saskatchewan	198,000	209,000	1055
Alberta	38,500	44,000	1145

* 1 hectare = 2.47 acres; 1 tonne = 1.1 ton; 1 kg./ha = .892 lb/ac.

EXPORTS

World flaxseed production is concentrated in Canada, the United States, Argentina, India and the U.S.S.R. These five countries comprise about 85% of the total world production. Canada is the leading exporter of flaxseed, while Argentina is the leading exporter of linseed oil. Because of its higher oil content and quality, Canadian flaxseed is preferred in the world market. In the period 1981-1985, exports of Canadian flaxseed averaged 531,000 tonnes (585,200 tons). Major buyers of Canadian flaxseed include the European Economic Community, Japan and the United States.

Canada exports over 75% of its total flaxseed production while approximately 10% goes into domestic crushing and 15% is accounted for by dockage and retention for seed purposes. Comparing the dollar value of flaxseed,linseed oil and meal exports, seed exports account for about 95% of the three commodities.

CROP ROTATION

Historically, flax has been sown into both summerfallow land and stubble land. The proportions for each have varied over time. In the past, it was generally recommended that flax be sown into relatively weed-free fallow land as flax is not very competitive against weeds. There was a lack of herbicides to selectively control broadleaf and grassy weeds, including volunteer

cereals. Today, however, a broad spectrum of herbicides is available that will do an excellent job of controlling both broadleaf and grassy weeds including volunteer cereals. Now farmers frequently refer to flax as a "clean-up crop" in rotations. Flax is predominately a stubble sown crop in Manitoba and is increasing as a stubble crop in Alberta and Saskatchewan. (Table 3)

TABLE 3

Average seeded area of flax and distribution on summerfallow and stubble in the prairie provinces, 1980-1984

Province	Average Area (ha*)	Sown On Fallow %	Sown On Stubble %
Alberta	45,000	53	47
Saskatchewan	200,000	44	56
Manitoba	355,000	6	94

* 1 ha = 2.47 ac.

Research in Saskatchewan has shown that flax sometimes does poorly after canola or mustard because of toxic compounds in mature plant and seedling residues. Research in Manitoba has shown that flax yields on canola stubble were generally not affected, although small reductions occurred in some years. The problem is most evident where straw and trash from the previous canola crop has not been adequately spread on the soil surface. Canola straw should, therefore, be spread uniformly and spring volunteer seedlings controlled at an early stage in order to minimize possible toxic effects.

Flax does well after cereals and corn. It also does well after legume crops, but **Rhizoctonia** disease may be a problem. Flax does not do well after potatoes and sugar beets because the soil may be too loose and **Rhizoctonia** disease could also be a problem. As a precaution, wait three years between flax crops, because of the risk of **Fusarium** wilt and other diseases.

BROWN AND DARK BROWN SOIL ZONES

Flax is well-adapted to and is widely grown on the Brown and Dark Brown soils of the prairies. However, flax leaves little residue on the land, thus increasing the risk of wind erosion if the land is summerfallowed after a flax crop. Flax should be followed by a cereal in the rotation.

In the past, poor flax yields were generally a result of drought and weed competition. However, most broadleaf and grassy weeds including volunteer cereals can now be controlled easily in flax with presently registered herbicides. With adequate weed control, the major factor influencing the yield of flax in a rotation for the Brown and Dark Brown soil zones is the availability of moisture.

Although lack of moisture limits yields it also allows for a high carryover of nutrients. Therefore it is important to fertilize according to soil testing for optimum returns from the addition of fertilizer.

BLACK AND GRAY BLACK SOIL ZONES

In the Black and Gray Black soil zones across the prairie, moisture is less of a yield-limiting factor than in the Brown and Dark Brown soil zones. Flax fits into a rotation easily, providing producers with an alternative to cereals and canola. Crop sequence studies at Melfort, Saskatchewan have shown that flax produced better on wheat and barley stubble than it did on canola, flax or oat stubble. At Indian Head, Saskatchewan, wheat following flax showed no reduction in yield, therefore, making wheat the most acceptable crop to follow flax. Barley also performed well on flax stubble.

VARIETIES

The characteristics of flax varieties commonly grown on the prairies are described in Table 4, while varietal yield performance is presented in Table 5. A brief description of the varieties is given below. For more information on the varieties recommended in your area, refer to provincial recommendations, which are published annually and which are available from provincial or federal departments of agriculture.

All flax varieties presently licenced in Canada are brown-seeded. Unlicenced yellow-seeded varieties are grown for use in various edible products and for the health food trade. Yellow-seeded varieties are generally higher in oil content than brown-seeded varieties, but are lower yielding.

EARLY VARIETIES

LINOTT is an early maturing variety that is particularly well adapted to late seeding but also does well in early seeding. It has a medium oil content and the oil is of fairly good quality. Linott has blue petals, colorless filaments and a colorless style with a blue base. It possesses the L^6 gene for rust resistance. Linott was developed by Agriculture Canada Research Station, Ottawa, Ontario from the cross (Ott. 770B/Argentine 8C)//(Arrow/C.I. 975). The variety was licenced in 1966.

NORALTA is early maturing and, consequently, is well adapted to northern flax production areas. Even though Noralta is early maturing, it does not do well in late seeding. The variety has a higher than normal tendency to drop mature bolls during high winds. It has a low oil content but the oil is of fairly good quality. Noralta has tall straw and fairly good resistance to lodging. It has light blue petals and colorless filaments and style. Noralta is susceptible to rust. The variety was developed by Agriculture Canada at Ottawa, Ontario, and Fort Vermilion, Alberta from the cross Redwing/Rocket. It was licenced in 1965.

MEDIUM-EARLY VARIETIES

CULBERT is particularly well adapted to late seeding in southern Manitoba. It does not perform as well in Saskatchewan and Alberta. Culbert has medium oil content and the oil is of good quality. The variety possesses the L^6 gene for rust resistance. Culbert was developed in the United States at the Minnesota Agricultural Extension Experiment Station, St. Paul, Minnesota from the cross Windom/Bison 70. It was licenced in Canada in 1978.

NORLIN is adapted to all areas of flax production of the Prairies. It is approximately 2 to 3 days later than Linott and Noralta. NorLin produces high yield in both early and late seeding. The variety has a medium oil content and the oil is of fairly good quality. It has persistent, blue petals, which are slightly darker than those of the other varieties, colorless filaments and colorless style with a blue base. The rust resistance of NorLin is conditioned by the L^6 gene. NorLin was developed by the Agriculture Canada Research Station, Morden, Manitoba from the cross (Rocket/Raja)//Linott. It was licenced in 1982.

NORMAN is similar in maturity to NorLin but it does not perform as well in late seeding. It is particularly well adapted to Manitoba. NorMan has a slightly higher than normal tendency to drop mature bolls during high winds. It has a high oil content but the oil is of fairly low quality. The variety has blue petals, filaments, and style. The rust resistance of NorMan is conditioned by the L^6 gene. NorMan was developed by the Agriculture Canada Research Station, Morden, Manitoba from crosses involving Linott, Noralta, Raja, Redwood and Valuta, an introduction from Sweden. It was licenced in 1984.

VIMY is a high yielding variety similar in maturity to NorLin and is particularly well adapted to Saskatchewan. It has weaker straw than other varieties and for this reason should not be considered for the Red River Valley or irrigation farming. Seed of Vimy has a high oil content of fairly good quality. The petals are blue while filaments and style are colorless. The rust resistance of Vimy is likely conditioned by the L^6 gene. Vimy was developed by the Crop Development Centre, University of Saskatchewan from a cross between Kubansky and Linott. It was licenced in 1986.

LATE VARIETIES

DUFFERIN is a late maturing variety that is high yielding when sown early. It is not recommended for late seeding. Dufferin tends to be variable for plant height and has to good-fair resistance to lodging. It has a high oil content and the oil is of fairly good quality. The variety has blue petals, filaments and style. Dufferin can be distinguished from other varieties by the non-hairy false septum of the boll. It possesses the K^1 gene for rust resistance. Dufferin was developed by the Agriculture Canada Research Station, Morden, Manitoba from crosses involving Raja, Redwood 65, Koto, Golden and Rio. Since its release in 1975, Dufferin has been the predominant variety in Manitoba and Saskatchewan.

McGREGOR is a high yielding, late maturing variety. It has very good lodging resistance, superior to all other varieties. The variety has a medium oil content and the oil is of fairly good quality. It has blue petals, filaments and style. McGregor is the only Canadian variety possessing two genes, K^1 and L^6, for rust resistance. McGregor was developed by the Agriculture Canada Research Station, Morden, Manitoba, from the cross Redwood 65//(Rocket/Raja). It was licenced in 1981.

SEED AND SEEDING PRACTICES

CHOICE OF LAND

Flax usually does well on types of land suitable for wheat. It grows best on heavy loam soils that retain moisture well. One disadvantage of heavy soils is their tendency to crust after heavy rains and interfere with the emergence of the seedlings. Because flax has a limited root system, it does not thrive on sandy soils unless a plentiful supply of moisture is available. Poorly drained land, or land subject to excessive drought or erosion should not be sown to flax. Flax is moderately tolerant to salinity provided that fertility levels are suitable and adequate moisture is available during germination.

CHOICE OF SEED

Use good, preferably certified seed of a recommended variety. Certified seed is tested to ensure minimal weed content, high genetic purity and good viability. It consistently outyields poorly cleaned seed and produces a higher net return from the crop. If farm-grown seed is used, it should be thoroughly cleaned to remove weed seeds and retain only sound kernels.

SEED DAMAGE AND EFFECT ON PLANT STANDS

Cracked, split and blighted seed is very common in samples of flaxseed, wherever the crop has been produced. The seed coat is fragile, and cracked seed is the result of mechanical damage when flax is threshed at too high a cylinder speed, or threshing when the seed is too dry (Fig. 1b). Large seeded varieties are more prone to cracking than small seeded varieties. Seed that may appear sound and whole to the naked eye may in reality be cracked when viewed under magnification. Cracks, however small, provide entry for penetration and infection by soil microorganisms. The amount of cracking varies with year and location, but is hardly affected by variety. The amount of cracked seed may range from a low percentage to as much as 50% or higher. Cracked seed is often the cause of poor stands.

Split seed refers to the condition when the two halves of the seedcoat have become separated at the small end with resultant exposure of the embryo (Fig. 6c). As in cracked seed, split seed is prone to attack by microorganisms. Splits may be observed with the unaided eye, but the extent of the injury is evident only from inspection under magnification. Splits develop while the seed in the boll is still immature. This abnormality is more prevalent in yellow seeded than in brown seeded varieties.

Blighted seed may be weathered and discolored, or may be shriveled (Fig. 6d). Weathered seed often has a gray dull cast, and may turn black, while the seedcoat is often rough due to adherence of boll tissue (Fig. 6e). Weathered seeds tend to adhere to each other in the boll, making threshing difficult at normal cylinder speeds. Shrivelled seed results from diseases such as rust, pasmo, **Fusarium** wilt, or stem break and browning, which cause premature ripening. Shrivelled seed is often moldy due to colonization by various saprophytic fungi. Black discoloration may be due to infection by species of **Alternaria,** or to freezing of immature seed. Frozen seed appears shiny black (Fig. 6f), as opposed to dull black for blighted seed.

While cracked, split, or blighted seed generally occur together in the same sample, the amount of each varies with weather conditions and farm practices.

Seedlings produced from damaged seed may germinate very slowly and may be weak, or show a variety of abnormalities. Common abnormalities include injured root tips, broken or cracked cotyledons, split hypocotyls, twin radicles, radicles trapped inside the seedcoat, and roots that are blunt, broken, long and spindly, or gnarled and distorted.

Reductions in stand must be expected when using untreated, damaged seed. Damaged seed is prone to decay by soil microorganisms, and seedlings that do emerge are weak and prone to develop seedling blight. Resulting stands will be poor, uneven, lack vigour, and low yielding.

SEED TREATMENT

Treatment of flax seed with a recommended fungicide (Table 6) is essential. Seed treatment reduces seed decay and seedling blight, increases plant vigour, and can increase stands by up to 100%, with a consequent increase in yield. Because of higher amounts of split seed, the response may be greater in yellow-seeded than in brown-seeded varieties. Embryos can be killed by prolonged contact with the chemical, and therefore, long term storage of treated seed should be avoided (see further Seedling Blight and Root Rot).

SEEDBED PREPARATION

Flax must be seeded into moist, firm soil. Seedbed preparation begins in the previous season on either summerfallowed or cropped land. For summerfallow operations, the intent should be to control weeds and preserve the trash cover. For stubble land, the straw from the previous crop should be chopped when threshing and spread uniformly. Unless fall tillage of the stubble is not recommended, the land should be worked in the fall in a way that minimizes soil drifting and provides effective snow trapping. If winter annual weeds such as stinkweed, flixweed or shepherd's purse are present, they should be controlled with an early fall application of 2,4-D at low rates. Spring tillage before seeding, whether on summerfallow or on stubble land, should be shallow in order to maintain a firm seedbed, conserve moisture, and avoid bringing weed seeds up into surface soil where they may germinate. If deep tillage is necessary, packing before or after seeding may be required. Sow the flax soon after the land is worked, before the soil dries out and before weed seeds have a chance to germinate.

Minimum and zero tillage practices are attractive because they provide protection from erosion, increase soil organic matter and improve moisture retention. In addition, they reduce crusting problems and consequently improve stands of flax. Good post emergence herbicides have made zero tillage more viable for flax than some other crops. However, specialized seeding equipment is required.

Fig. 1. *Flax plant*

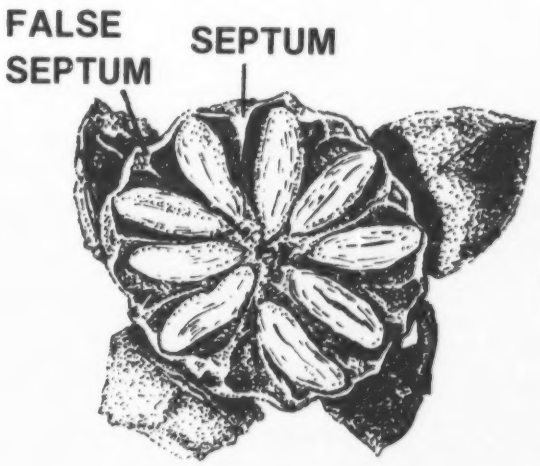
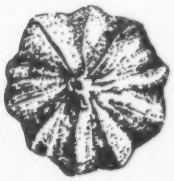
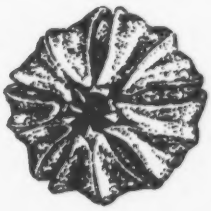


Fig. 3. *Cross section of a flax boll showing 9 of a possible 10 seeds in 5 segments.*



a) closed



b) semi-dehiscent

Fig. 4 *Mature flax boll*

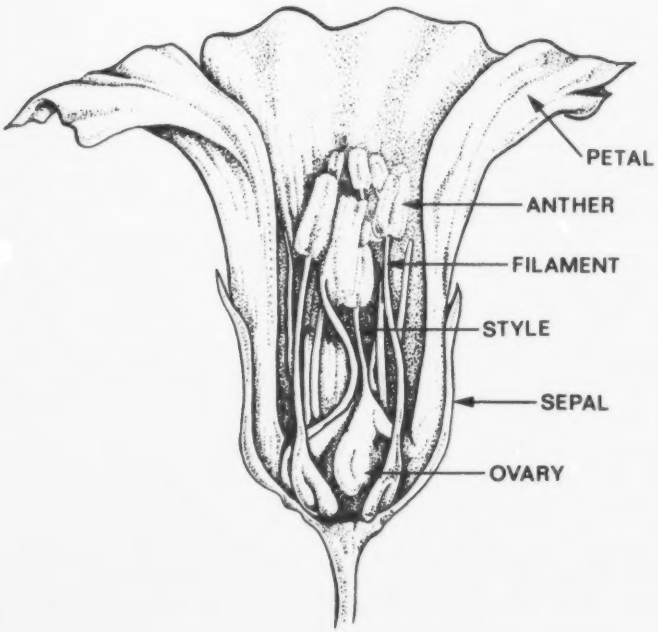


Fig. 2. *Longitudinal section of a flax flower*

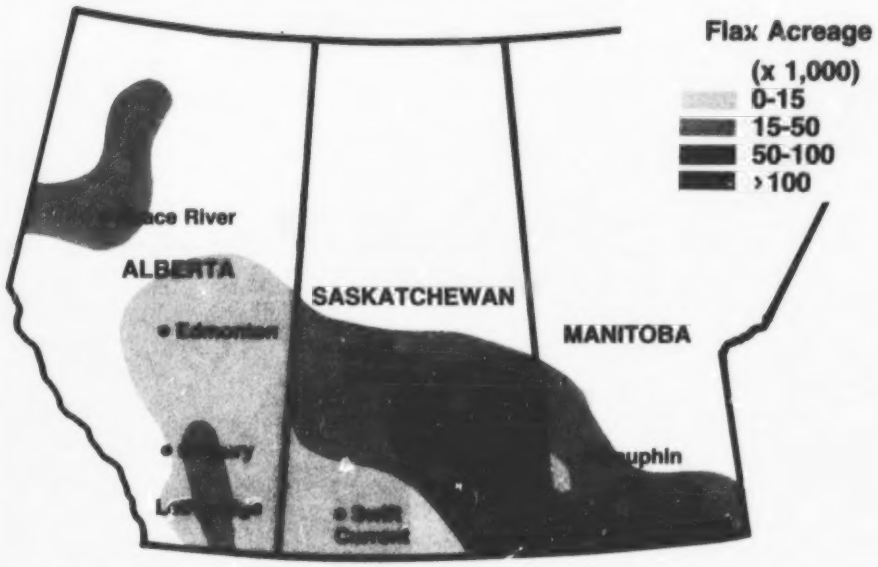
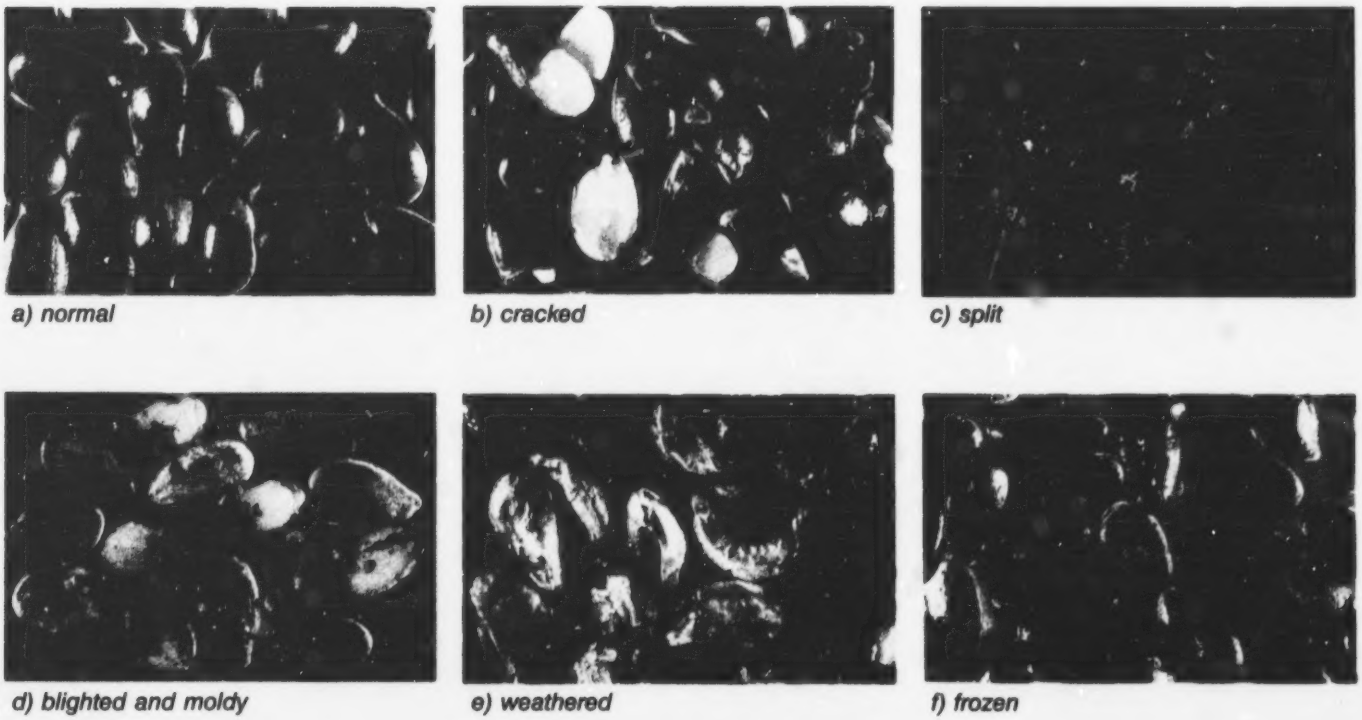


Fig. 5. *Flax production areas of the prairies.*

Fig. 6. *Seed condition:*



a) normal *b) cracked* *c) split*

d) blighted and moldy *e) weathered* *f) frozen*

Fig. 7. *Flax bollworm (within boll)*

Fig. 8. *Flax bollworm (outside boll)*

Fig. 9. *Red-backed cutworm*

Fig. 10. *Early cutworm*

Fig. 11. *Bertha armyworm*

Fig. 12. *Beet webworm moth*

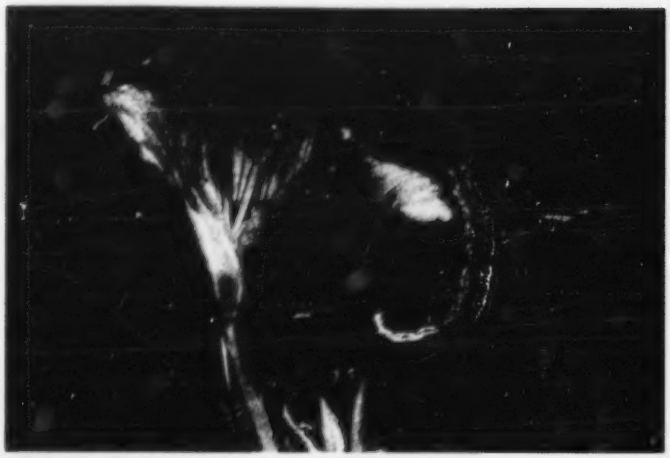


Fig. 13. *Beet webworm caterpillar*

Fig. 14. *Tarnished plant bug*

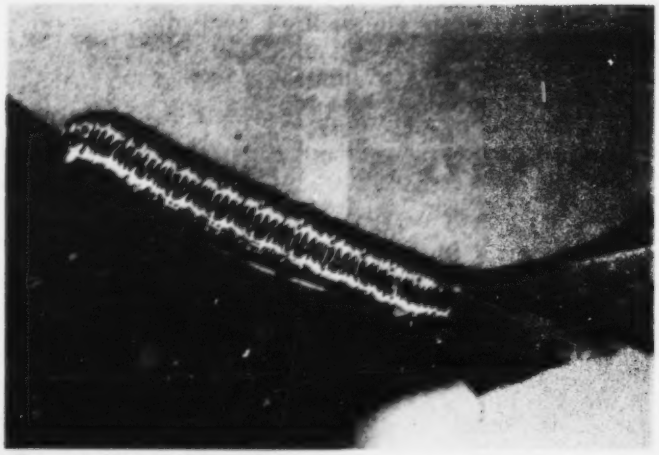


Fig. 15. *Zebra caterpillar*

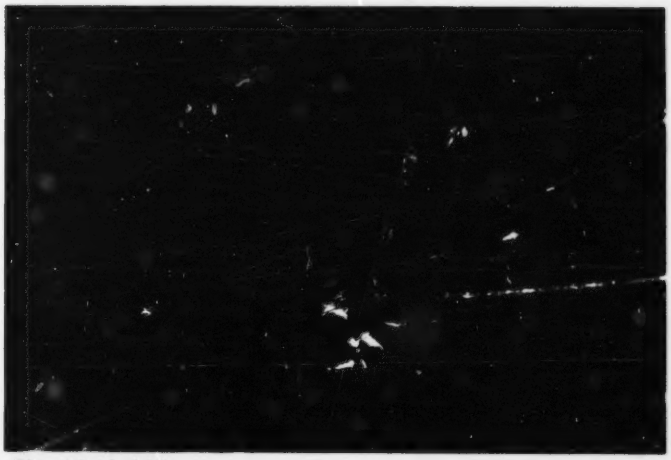


Fig. 16. *Aphids*

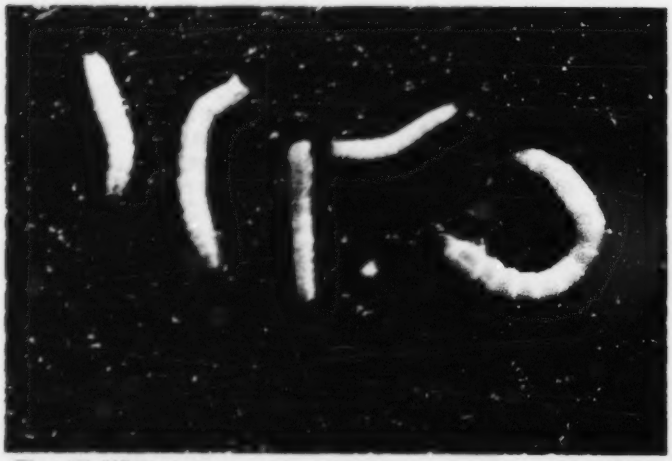


Fig. 17. *Wireworms*

Fig. 18. *Variegated fritillary - adult*

Fig. 19. *larvae*

Fig. 20. *Rust; numerous orange uredia on leaves.*

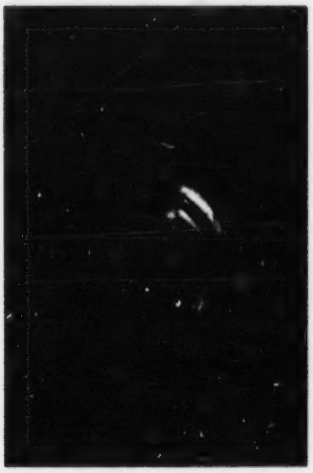


Fig. 21. *Rust; orange (summerstage) and black (overwintering stage) on flax boll.*

Fig. 22. *Fusarium wilt; dead (brown) and wilting (yellow) plants.*

Fig. 23. *Pasmo; alternating green and brown (infected) bands on the stem.*

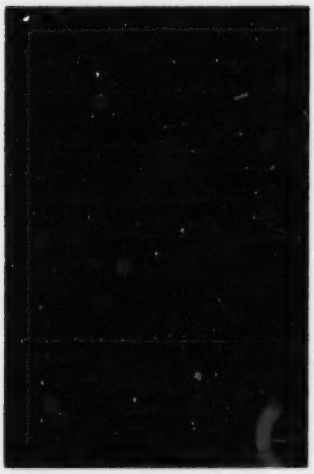


Fig. 24. *Stem break and browning; plants often break at the canker that weakens the stem base.*

Fig. 25. *Aster yellows in in the field*

Fig. 26. *Aster yellows; flowers are sterile*

Fig. 27. *Heat and frost canker; stems at the soil line are girdled.*

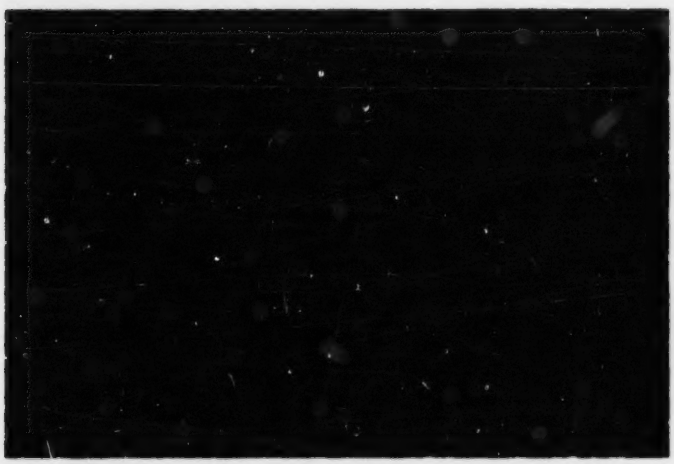


Fig. 28. *Heat and frost canker; plants have toppled over.*

Fig. 29. *Straw bunching unit.*

METHOD OF SEEDING

Flax should be sown shallow, 2.5-4 cm (1-1.5 in.) deep, with a drill that places the seed at a uniform depth in rows 15-20 cm (6-8 in.) apart. The most satisfactory results are achieved by using a drill equipped with press wheels which firm the soil around the seed. If a drill does not have press wheels, a soil packer may be drawn behind the drill, or the field may be packed in a separate operation. Seeds that are placed at a uniform shallow depth in firm, moist soil will germinate and emerge evenly and rapidly. Under dry soil conditions, it may be necessary to seed deeper than 4 cm (1.5 in.) in order to place the seeds in moist soil. However, deep seeding should be avoided whenever possible as emergence will be delayed, and result in weak seedlings and reduced stands. Weak seedlings are more prone to injury from preplant incorporated herbicides. Furthermore, deep seeding increases the risk of crusting if heavy rain occurs before seedlings emerge. Flax seedlings are less able than wheat seedlings to force their way through surface crusts. Hence, harrowing is occasionally necessary to facilitate emergence of seedlings.

RATE OF SEEDING

In tests conducted in Saskatchewan and Manitoba, flax showed little yield response to changes in seeding rate from 25-55 kg/ha (22-49 lb/ac). In the prairie provinces, a seeding rate of 30-45 kg/ha (27-40 lb/ac) is recommended. In eastern Canada or on land under irrigation, as much as 50 kg/ha (45 lb/ac) can be sown as more moisture is usually available to support a larger crop. The seeding rate should be adjusted according to size of seed, germination percentage, soil fertility, or weediness. Higher seeding rates may be required for yellow-seeded varieties, particularly if seed treatment is not applied as would be the case for flax grown for the organic food market.

PLANT STAND

If seedling stands are thin, a decision must be made whether to reseed or not. Flax seedling emergence is sometimes poor due to weak seed, soil crusting, seedling diseases, adverse weather conditions, deep seeding, herbicide injury, or other reasons. A seeding rate of 30-45 kg/ha (27-40 lb/ac) provides approximately 500-800 seeds/m². Studies at Morden, Manitoba, have shown that yields were not affected by reduction in plant stands from 500 to 300 plants/m², but yields generally tended to drop off as stands dropped below 300 plants/m² (Table 7). However, even at plant stands as low as 100 plants/m², yields were reasonably good due to extensive tillering. It is possible that those yields would still be better than those from a reseeded crop considering that yields are generally lower the later the seeding date, and lower because of loss of soil moisture from additional tillage. Also, the added costs of reseeding must be taken into account.

TABLE 7
Plant stand counts and seed yield of linott averaged for 1971 and 1972

Plants/m²	% Yield Reduction from 500 plants/m²
500	-
400	2
300	2
200	8
100	11

SEEDING DATE

Early seeding of flax generally produces the best results. Flax is seldom damaged by light spring frosts. Moderate temperatures and ample soil moisture during flowering and when seeds are developing, favor high yield, high oil content and high oil quality. Such conditions are more likely to occur when flax is seeded early. High quality straw for fibre is more likely to be obtained when flax is seeded early.

Late seeding of flax often results in much lower yields. Tests in Manitoba showed that compared to early seeding in May, a delay of seeding to June 1, June 10 and June 20 resulted in respective yield reductions of 7, 29 and 52% (Table 8). Late seeding also reduces oil content and seed size. Because green stems and second growth are more prevalent in a late-seeded crop, harvesting is more difficult. However, a delay in seeding of flax may be necessary if herbicides are not used to control early starting weeds such as wild oats, or when drought or excessive moisture have delayed field work. When seeding is delayed until after June 1, only early maturing varieties are recommended because of the risk of fall frosts. Flax varieties differ in their performance under conditions of late seeding. Tests in Manitoba have shown that of the earlier varieties, Culbert, Linott and NorLin will produce higher yields than Noralta and NorMan in late seeding (Table 8).

Spring frosts seldom damage flax seedlings. Plants just emerging are the most tender, but can withstand temperatures down to approximately -3° C (27° F). After the seedlings have passed the two-leaf stage and are hardened by exposure, they can withstand temperatures as

low as -8° C (18° F) for a short time without damage. Unlike cereals, where the growing point of the seedling is protected under the soil surface, the growing point of the flax seedling is fully exposed above the ground and is more vulnerable to frost.

FERTILIZER PRACTICES

Nutrient levels in the soil vary greatly among regions and soil types, and with cropping history. Soil tests and experience should guide fertilizer use decisions. Provincial fertilizer bulletins should be referred to for general recommendations regarding fertilizer requirements, rates, and placement.

Flax is very sensitive to seed-placed fertilizer, with even low rates sometimes causing seedling injury. Some provinces recommend that only a low rate of phosphate not more than 20 kg/ha (18 lb/ac) of P_2O_5 may be seed-placed while others recommend that no fertilizer be placed with the seed of flax.

Flax often responds well to nitrogen (N) fertilizer application when available soil N is low. For flax seeded on stubble, 35 to 80 kg/ha (31-71 lb/ac) of N should be applied unless more specific information, such as a valid soil test, indicates otherwise. Select a rate from within the suggested range based on moisture conditions, using the lower end of the range when yield is expected to be limited by drought. Response to N fertilization is less frequent for flax seeded on fallowed land, and would be most likely in wet years, i.e. when the yield potential is high in comparison to the available N supply. The relative effectiveness of the various N sources, forms, placements and application times is the same for flax as for other annual crops. N should not be placed directly with the seed.

Response of flax to phosphorus (P) fertilization is less pronounced or consistent than for most other annual crops. The flax plant appears to prefer high soil P levels resulting from optimum P fertilization of preceeding crops, as compared to the application of a high rate of P for the flax crop itself. Rates of up to approximately 35 kg/ha (31 lb/ac) of P_2O_5 are recommended for flax on soils with low levels of available P. Phosphate banded 2.5 cm (1 in.) directly below the flax seed row has been the most effective; sidebanding 2.5 cm (1 in.) below and 2.5 cm (1 in.) to one side of the seed row is also often effective. Pre-plant deep-banding of P, which is often a good placement method for other crops, has not been fully evaluated for flax. Broadcasting and incorporation of P fertilizer for flax is ineffective, with up to fourfold increase in application rates required to achieve the same yield increase as that obtained with sideband placement. The performance of P placed with the seed in the wider bands behind hoe-type row openers is being evaluated.

Deficiencies of potassium (K) and sulphur (S) can limit production of all crops. However, these deficiencies are much more limited in extent than those of N and P, and are usually associated with specific soil types. Sandier soils of the Gray and Gray-Black soil zones, as well as organic soils, are most frequently deficient in K. Sulphur deficiency is slightly more extensive, and can occur on sandy to loam soils of the Black through Gray Soil Zones.

Flax is more sensitive to low levels of iron and zinc in the soil than are most other western Canadian field crops. In wet soil conditions, temporary iron deficiency can cause chlorosis (yellowing of the leaves) in irregular patterns in the field. However, field tests have seldom shown any flax yield increase attributable to application of these micronutrients to flax. Therefore, field scale micronutrient fertilization of flax is not recommended.

INSECT PESTS

Flax may be infested from the time of emergence to maturity by various insect pests. To keep damage low, fields should be examined regularly and controls applied when infestations reach the economic threshold. The following species are potentially damaging but often occur in too low number to cause economic loss.

PEST OF FLAX ONLY

The flax bollworm, **Heliothis ononis** (Denis & Schiffermiller), is a climbing cutworm. Flax is the only crop it attacks. The moths deposit their eggs in the open flowers, and the young larvae eat the developing seed within the boll (Fig. 7). The older green and white striped worms leave the boll and complete development by feeding on other bolls from the outside (Fig. 8). Economic infestations of this pest have so far been limited to west central Saskatchewan.

PESTS OF FLAX AND OTHER CROPS

Two subterranean species of cutworms, the red-backed **Euxoa ochrogaster** (Guen.) (Fig. 9), the pale western, **Agrotis orthogonia** (Morr.), and the early cutworm, **Euxoa tristicula** (Fig. 10), attack flax. The adult moths of these species lay eggs on the soil surface in weedy summerfallow fields during late summer. These eggs overwinter and the young larvae feed on flax seedlings in the spring. Cutworms usually remain below ground, cut off the young plants near the soil surface and draw them down where they are eaten. An average population of three red-backed cutworms per square foot can cause complete destruction of a field of flax.

Larvae of the army cutworm, **Chorizagrotis auxiliaris** (Grote), damage flax and many other crops by feeding on foliage in the spring, and to a lesser degree, in the fall. It is an important pest in southern Alberta and, to a lesser extent, in southern Saskatchewan. Populations of only a few larvae per square foot can cause significant damage.

Grasshoppers are a hazard to flax. Young grasshoppers may attack young plants and cause damage. However, more damage is done to the crop before harvest by the older, larger grasshoppers. They can quickly cause large numbers of bolls to drop by chewing through the more succulent portions of the stem below the bolls.

The bertha armyworm, **Mamestra configurata** (Walker) (Fig. 11), was a regular pest of flax before canola and mustard were grown on the Prairies. However, since the widespread introduction of the **Brassica** crops, the bertha armyworm rarely causes economic damage to weed-free flax fields. If bertha armyworm infested canola fields are swathed and green flax fields are nearby, the flax can then suffer significant damage from invading larvae. When abundant, bertha armyworms cause serious damage by chewing through the stems below the bolls causing them to drop to the ground. Young bertha larvae are green but larger larvae are usually velvet-black.

The beet webworm, **Loxostege sticticalis** (Linnaeus) (Fig. 12), is a slim, active, dark-green caterpillar which eats leaves, flowers and patches of bark from flax stems and branches (Fig. 13). Localized areas can suffer severe damage. Determine if a significant number of bolls are being damaged before applying controls.

The aster leafhopper, **Macrosteles quadrilineatus** (Fbs.), and the tarnished plant bug, **Lygus lineolaris** (Palisot de Beauvois) (Fig. 14) can also damage flax. These insects, like aphids, feed by sucking juices from the flax plants. Leafhoppers can carry aster yellows mycoplasm and also crinkle virus, and can infect the plants with these diseases while feeding. Tarnished plant bugs damage flax by feeding on the growing tips, which become distorted and die back. The damage from these insects is most serious on late-seeded crops.

MINOR PESTS OF FLAX

A climbing cutworm, **Polia lilacina** (Harv.) has been widely distributed in flax fields in Saskatchewan and Alberta but apparently has not caused significant damage.

The zebra caterpillar, **Ceramica picta** (Harr.) (Fig. 15), is another species which feeds on flax as well as many other crop plants. This is not normally a significant pest.

Aphids (Fig. 16), are potentially a pest of flax and large numbers can often be seen on the leaves. However, in most years their numbers are not sufficiently high, and the build-up is too late to cause a significant reduction in yield. Aphid populations are usually controlled by a large variety of insect predators and parasites.

Wireworms (Fig. 17), although often serious pests of cereal grains in the seedling stage, seldom damage flax.

The adults and larvae of the variegated fritillary, **Euptoieta claudia** (Cram.) (Fig. 18 and 19), have been recorded on flax. However, this insect is usually not sufficiently abundant to cause economic damage.

For more information on insects and their damage, and for up-to-date information on control, consult district agriculturists, agricultural representatives or provincial entomologists.

Current recommendations for chemical control of insects of field crops are published annually by most provinces. Labels on pesticide containers also provide essential information on application procedures and pesticide safety, and should be followed closely.

CONTROL OF WEEDS

Weeds can be a serious problem in flax crops if left uncontrolled. Because flax does not shade the ground as much as cereal grains, weeds have an excellent chance to develop. Some weeds like wild buckwheat are luxury users of nitrogen and will rob the flax crop of needed soil nutrients.

Weeds not only compete with the growing flax crops to reduce yields, but also cause losses from dockage in seed shipments. Dockage amounts to thousands of tons annually and is charged directly against marketing costs. Dockage is also objectionable because weed seeds absorb oil during crushing. Weeds will render flax straw unusable for paper making which has become an important industry in the eastern prairies.

Many herbicides are available for the control of weeds in flax. Some are applied preplant soil incorporated, while others are applied postemergence. Because of a relatively wide selection of herbicides, flax is now sometimes used as a clean-up crop. When using postemergence herbicides, apply them within the period and under the conditions recom-

mended on the herbicide label and as soon as enough weeds have emerged to make application practical. Early removal of weeds is necessary to minimize crop losses caused by weed competition. Weeds in the seedling stage are generally more susceptible to herbicides than at any other stage, and the risk of crop injury is usually decreased by early treatment. Risk of injury is also reduced by using spray volumes of at least 112 litres/ha (10 gal/ac) for most herbicides. The performance of many herbicides can also be affected by soil moisture conditions, air and soil temperatures, and other environmental factors.

Weed control recommendations for flax are published annually by provincial Departments of Agriculture. For these publications and for the latest information and specific recommendations for your area, consult your local agricultural representative or weed supervisor. **Always read and follow instructions carefully when using herbicides.**

Several cultural practices can also be followed to reduce weed problems in flax and to reduce the amount of herbicides required. Always sow thoroughly cleaned seed and follow recommended crop rotation practices. Cultivate immediately after harvest, where possible, to promote germination of weed seeds and volunteers before freeze-up. Spring tillage to promote germination of weed seeds before seeding may help. The first tillage should be no deeper than about 10 cm (4 in.), and all subsequent tillages should be less deep than the first to avoid bringing up more weed seeds. If these spring cultivation practices are followed, only early maturing flax varieties should be selected.

DISEASES

Historically, Fusarium wilt and rust disease have been limiting factors in flax production. In western Canada, as flax production rapidly expanded at the turn of the century, Fusarium wilt, a soilborne disease, became a major problem because crop rotation was hardly practiced, and because varieties grown at the time were susceptible to this disease. Breeding for resistance became a major objective, and with the development of new, wilt-resistant varieties, the wilt danger receded. Wilt-susceptible varieties were replaced during the 1930's by the wilt-resistant Bison and Royal, and the semi-resistant Redwing. Bison was unfortunately highly susceptible to rust, and the build-up of the rust pathogen during the 1930's culminated during the 1940's and early 1950's in repeated, severe epidemics producing new rust races that attacked hitherto resistant varieties. More recent outbreaks of new rust races occurred in 1962 and in 1973. Over a 40 year period, 13 varieties licenced in Canada had to be replaced because of susceptibility to new races. Breeding for resistance to rust and wilt are still major objectives in the development of new varieties.

RUST

Rust is potentially the most dangerous disease affecting flax. Rust is caused by **Melampsora lini**, a fungus that overwinters by means of teliospores carried on soilborne flax debris. The disease organism is a constant threat to flax production because of its ability to produce new races that attack hitherto resistant varieties. Rust is readily recognized by the presence of bright orange, powdery pustules, also called uredia (Fig. 20), that develop on stems but mostly on the underside of the leaves, as well as on the bolls (Fig. 21), later in the season. The powdery pustules produce numerous uredospores which are airborne and cause new infections. Spread of rust is favored by high humidity during cool nights, warmer day temperatures, and by vigorous plant growth. As the season progresses, the orange pustules turn black (Fig. 21), and produce the overwintering teliospores. The black pustules are most conspicuous on the stems. Flax rust completes its life cycle on the flax plant alone, unlike many other rusts that require an alternate host.

Complete control of the disease is offered by the use of resistant varieties (see Table 4 - VARIETIES). Planting a susceptible variety may not only result in serious yield loss, but also affords the rust fungus a chance to produce new races that attack other, hitherto resistant, varieties. Use of certified seed of a recommended variety, planting the new flax crop in a field distant from that of the previous year, and crop rotation are additional safeguards.

FUSARIUM WILT

Flax wilt is caused by the seed- and soilborne fungus **Fusarium oxysporum** f.sp. **lini.** The organism invades plants through the roots, and continues growth inside the water conducting tissue of the plant. While seedlings may be killed shortly after emergence, delayed infections cause yellowing and wilting of leaves, followed by browning and death of the plant (Fig. 22). Roots of dead plants turn ashy gray. The tops of wilted plants often turn downward, and form a "shepherd's crook". Affected plants may be scattered through the field but they occur more commonly in patches. The wilt organism interferes with water uptake, and warm weather therefore aggravates the disease. The fungus is persistent in the soil and survives for many years on debris of flax and other organic tissue. Recommended varieties are at least moderately

resistant, and reports of yield losses due to wilt are rare. A most important control measure is a crop rotation of at least 3 years between flax crops.

PASMO

The causal organism of pasmo disease is **Septoria linicola,** a fungus that overwinters in the soil on old, infected flax stubble. The debris carries numerous pycnidia, tiny, black fruiting bodies, that produce masses of spores that cause the initial infection on the leaves. The disease in advanced stages is characterized by the development of circular, brown lesions on the leaves, and the occurence of brown to black infected bands that alternate with green, still healthy bands on the stem (Fig. 23). Infected areas are occupied by pycnidia, and the spores produced are carried by rain and wind to cause new infections. High moisture and warm temperatures favor the disease, and pasmo can cause defoliation and premature ripening, with resultant reduction in yield and seed quality. Lodging favors the development of pasmo, presumably because of increased humidity. The disease is more common in Manitoba with its moist climate than in the drier production areas of Alberta and Saskatchewan. Flax is most susceptible to pasmo in the ripening stage. Commercial varieties lack resistance, and the best control of pasmo is achieved by seeding early, using clean seed, treating seed with a recommended fungicide, and using a rotation of at least 3 years between flax crops.

STEM BREAK AND BROWNING

Stem break and browning are phases of a disease caused by the seedborne and soilborne fungus **Aureobasidium pullulans** var. **lini,** also called **Polyspora lini.** Initial infections in spring may start from spores produced on diseased stubble, and are spread by wind and rain. More importantly, infections may start during seedling emergence when seed coats of diseased seed are lifted above the ground, and the fungus produces the first spores of the new season. Stem break is the first conspicuous disease symptom. Development of a canker at the stem base weakens the plant, and the stem may break at this point when the plants are still young (Fig. 24), or stem break may be delayed. Plants may remain alive after falling over, but any seed produced may still be lost in harvesting. The browning phase is initiated by infections on the upper part of the stem that appears as oval or elongate brown spots, often surrounded by narrow, purplish margins. The spots may coalesce, and leaves and stem turn brown. Patches of heavily infected plants appear brown, giving the disease the name of browning. The fungus may penetrate the bolls, as well as the seeds, or may produce spores on the seed surface. However, affected seeds may remain viable.

Use of clean seed produced by healthy plants is the most important control measure. Fungicidal seed treatment controls surface-born inoculum, but is unlikely to be effective against inoculum borne inside the seed. Rotating crops and planting flax in a field distant from that of the previous year would reduce spread of infection from diseased stubble. Currently recommended varieties may differ in susceptibility to stem break and browning.

SEEDLING BLIGHT AND ROOT ROT

In spite of seed treatment, seedling blight and root rot can develop, and cause reductions in yield. Blighted seedlings may occur singly or in patches. Affected seedlings turn yellow, wilt, and die. Seedling blight may be inconspicuous, and gaps in the row may be the principal sign of disease occurence. The roots of recently affected plants show red to brown lesions, and may later turn dark and shrivel. Diseased plants are often difficult to distinquish from those killed by the wilt fungus (Fig. 22). Root rot symptoms appear in plants after the flowering stage. Plants may wilt on warm days, and turn brown prematurely; plants with root rot usually set few or no seeds. Seedling blight and root rot may be due to soilborne fungi such as species of **Fusarium** and **Pythium.** Disease due to **Pythium** is promoted by cool, wet conditions. The principal agent, however, is **Rhizoctonia solani,** which can be particularly destructive in soils that are loose, warm and moist. **R. solani** is a soilborne fungus, and survives as a composite of strains that differ in host range and pathogenicity. Strains attacking sugarbeets and legumes such as alfalfa and field peas also attack flax. Yellow-seeded varieties are more prone to blight and root rot than are brown-seeded varieties. The variety Linott is reported to be resistant to **Rhizoctonia** blight. The reactions of other varieties are not known.

Seedling blight and root rot can be controlled by a combination of farm practices. Reduce cracking of seed by proper combine settings. Treat the seed with a recommended fungicide at the recommer.ded rate. Avoid legumes and sugarbeets in the rotation. Practice a rotation of at least three years between flax crops, and plant in a field that is distant from fields sown to flax in the previous year. Use certified seed of a recommended variety. Provide a firm seedbed, and use recommended fertilizer and seeding practices to promote good, vigorous stands. Sow flax on second-crop land rather than on summerfallow.

ASTER YELLOWS

The six-spotted leafhopper is the main vector that transmits the mycoplasm organism that causes aster yellows in flax and in many other crops such as canola and sunflower, and in some weeds. The disease occurs annually but usually in trace amounts only. However, an epidemic in 1957 caused widespread severe yield losses in flax and other crops. Aster yellows symptoms in flax include yellowing of the top part of the plant, conspicuous malformation of the flowers, and stunted growth (Fig. 25). All flower parts including the petals are converted into small, yellowish green leaves (Fig. 26). Diseased flowers are sterile and seed is not produced. The severity of the disease depends on the stage at which plants become infected, as well as the number of insect vectors that carry the mycoplasm. The earlier the infection, the more serious the disease. The mycoplasm overwinters in perennial broadleaved weeds and crops, but most infections are carried by leafhoppers that migrate from the United States. Early seeding tends to reduce the incidence and severity of aster yellows. Only traces of the disease commonly occur in flax in western Canada.

CRINKLE

Like aster yellows, crinkle is a disease of flax that depends for infection on transmission by the six-spotted leafhopper. Crinkle is caused by a virus, called oat blue dwarf, that also causes disease in oats, wheat and barley. Crinkle is characterized by a conspicuous puckering of leaves, as well as by stunted growth and reduced tillering. Flowering may appear normal but seed production is reduced. Only traces of the disease commonly occur on flax in western Canada.

MINOR DISEASES

In certain localities, occasional fungal diseases may be due to **Alternaria linicola** causing seedling and stem blight, **Collectotrichum lini** causing anthraconose of leaves and seedling blight, **Phoma exigua** causing root rot, and **Selenophoma linicola** causing dieback. The **Alternaria** and **Colletotrichum** pathogens are seedborne, and may be controlled by fungicidal treatment. There is a single record of **Sclerotinia sclerotiorum,** which caused stem mold in dense plantings of fibre flax in Alberta.

PHYSIOLOGICAL DISORDERS

CHLOROSIS AND TOP DIEBACK

Leaf chlorosis, dieback of terminal buds, and development of lateral branches from the lower stem are associated with deficiencies in trace elements such as zinc and iron. These disorders are often found on soils rich in lime and are most severe under cool, moist soil conditions. Chlorosis of leaves may also occur in flax on waterlogged soils.

HEAT AND FROST CANKER

Very high and freezing temperatures can cause cankers at the stem base of seedling flax. While the damage is commonly inconspicuous, stands may be reduced by as much as 50%. Damage is usually most severe in thin stands on light soils. Frost cankers are similar to heat cankers in appearance but are caused by freezing temperatures at the soil surface. Low spots are most conducive to frost canker. Plants affected by heat or frost canker are girdled at or near the soil line (Fig. 27). The area below the constriction is usually thin and dry, while that above it consists of scar tissue which may appear swollen, rough and cracked. This scar tissue is brittle, and affected plants usually fall over (Fig. 28). Less severely damaged plants may produce new shoots which grow to maturity, or they may topple over later in the season, turn yellow, and die. The incidence of heat and frost canker is reduced by following proper seeding practices that ensure, good, vigorous stands. Seeding early, at a high rate, and in a north-south direction is recommended on soils where these disorders can be a problem.

INJURY DUE TO HERBICIDES

Some herbicides can cause injury to flax when applied under certain environmental conditions such as high humidity, low soil moisture, temperature extremes, or other conditions of stress. MCPA (amine, sodium or potassium salts, or mixtures) can cause bending and twisting of stems, yellowing of leaves, and can delay maturity. Temporary leaf yellowing may also result from cyanazine/MCPA (Blagal) treatment. Trifluralin applied in the fall may cause stand thinning and delayed emergence of flax the following spring. Bromoxynil (Buctril M, Brominal M, Bromox 450M, Sabre, Torch) may cause suppression of flax growth for a short period after treatment, and delay maturity. The above described injury will usually be more than offset by increased seed yields resulting from reduced weed competition.

HARVESTING AND THRESHING

Flax may be harvested by straight combining or by cutting with a swather and threshing later with a combine. Straight combining is the preferred method if the crop is thoroughly dry and free of weeds. Swathing followed by combining has become popular because this

method assures drier seed than with straight combining, particularly if the crop is not uniformly mature or if weeds are present.

Flax is considered to be fully mature when 75% of the bolls have turned brown. After this stage has been reached, the crop may be swathed. If regrowth occurs in the fall, cut the crop when the greatest amount of ripe seed can be obtained. Do not delay the harvest too long because fall rains may cause weathering of the mature seed and frost may cause immature seed to turn black, resulting in a reduction in grade. Stems and leaves of mature flax can withstand temperatures as low as -9° C (16°F), but immature seed may be frozen by as light a frost as -1° C (30°F). Cutting or desiccating flax at an immature stage is not known to result in seed blackening, but yields will be reduced due to early termination of seed development. This will result in thin seeds of lower weight.

When swathing, leave a stubble of about 10 - 15 cm (4-6 in.) to hold the swath off the ground and facilitate drying. To prevent blowing by strong winds flax swaths should be rolled. Swathed flax may be ready to combine after exposure to a few days of dry weather. The swath may be threshed when the leaves and stems are dry enough and the seeds rattle in the boll or the seed has dried to the desired moisture level as indicated by a moisture meter. Although seed is considered dry enough for storage at 10.5% moisture, the crop may be harvested at a higher seed moisture if drying facilities are available. Usually, early-sown flax is easier to thresh than late-sown flax because it has a better chance to mature under drier conditions.

Keep the cutter bars of combines or swathers clean and sharp to ensure a smooth cut and to prevent accumulation of immature flax under the knife. Gumming of the cutting parts can be reduced by frequent application of water or kerosene.

Chemical desiccation may be used to accelerate drying of the crop and any weeds that may be present. It does not speed crop maturity but will reduce the time from maturity to harvest. Potential advantages from this practice are earlier harvesting, elimination of the need for swathing, reduction in combining time, less wear and tear on machinery, cleaner seed, and reduction or elimination of the need for artificial drying. A desiccant may be applied after 75% of the bolls have turned brown, which is, the normal time of swathing. Studies at Morden, Manitoba, with diquat have shown that yields are reduced if applications are made too early. For instance, diquat applied at the 25 and 50% brown boll stages, reduced yields as much as 20%, due to premature termination of development of some of the seed. Desiccated flax should be harvested as soon as possible after it is ready, to avoid weathering of the seed. For the latest information and specific recommendations on desiccants, consult your local agricultural representative.

It is important that combine adjustments are correct for threshing flax. The seedcoat of flax is easily broken during threshing, particularly if the cylinder speed is too high and the seed is very dry. Damaged seed has reduced germination. If the seed is to be used for planting, great care in threshing is required. Yellow-seeded varieties are more susceptible to seed damage because of their thinner seedcoat. It may be necessary to adjust the combine from time to time during the day depending on temperature, relative humidity and the condition of the flax. The manual provided with the combine should be consulted for correct settings. As a general guide, the front concave and the cylinder may be set about half as far apart as for wheat, from 3.2 to 6.4 or 8.0 mm (1/8 to 1/4 or 5/16 in.) depending on threshing conditions. A rear clearance ranging from 1.6 to 3.2 mm (1/16 to 1/8 in.) may be used. Use the widest spacings that will remove the seed from the bolls. The cylinder may be run at about 1830 m/min. (6000 ft./min.) or slower if the flax is very dry.

MANAGEMENT OF FLAX STRAW

Producers may choose one of several methods of handling flax straw. Spreading the unchopped straw is an undesirable method because the long fibrous stems remain intact for several years. This poses problems for harrow type operations which are common during seedbed and packing operations. Chopping and spreading the flax straw is more desirable. The chopping allows the straw to decompose quickly and be less of a problem during field operations.

A common method, although wasteful, is to bunch and burn the crop residues. There are several methods in which this can be accomplished. Some producers bunch the straw with front-end loaders or other common farm equipment such as self-propelled swathers. However, this can be hard on the machinery. One of the latest innovations by a Saskatchewan flax grower is a straw buncher that is pulled directly behind the combine. This buncher is controlled by the combine operator. This unit can also be pulled by a tractor after harvest, but bunching during the combining operation is more efficient (See Fig. 29)

Another method involves dropping the straw in windrows behind the combine and baling. Some quantity of this straw is purchased each year by fibre flax processing companies with the end

use being short fibre for various paper products. For this purpose, a tall lodging-resistant variety is preferred. The crop should be relatively weed-free and the straw mature.

Another use of baled flax straw is for rumminant livestock feed, primarily beef animals. Please refer to page 4 of this publication.

Recent research has indicated that none of the methods discussed in this section appear to affect the yield of a succeeding crop of wheat. The producer must make a decision as to the method that best fits his own operation and management. However, if the crop residues are removed by burning or baling, producers must keep in mind that the soil will become more vulnerable to erosion if summerfallow succeeds flax. Therefore, an additional cereal crop following flax is required to rebuild crop residues. Where continuous cropping is practiced, shortage of crop residues becomes less of a concern.

STORAGE AND CLEANING OF SEED

The percentage of flax grading Canada #1 is frequently very high, but dockage is often up to 10%. Dockage can be reduced by controlling broadleaf weeds as well as grassy weeds including volunteer cereals. If green weed seeds are present, they may raise the moisture of the flax seed enough to cause heating and molding. Removing this dockage before putting the flax into long term storage is advisable.

Flax can be safely stored at seed moisture levels of 10.5% or lower. Tough flax seed contains from 10.6 to 13.5% moisture; damp flax seed is over 13.5% moisture. Stored flax requires more attention than does stored wheat. Freshly harvested seed can maintain a high respiration rate for up to six weeks before becoming dormant. This, coupled with mold growth if the relative humidity of the air in the spaces between the seeds rises above 75%, can lead to heating. Once flax starts heating in a pocket, it will spread quickly and possibly throughout the entire bin. Each year, some heated flax shows up in the delivery system, but the percentage is very small. However, a wet harvest or an early fall frost will increase the percentage of heated flax in the delivery system. For this reason, flax should be cooled down after it is put into storage. If aeration equipment is not available, bins of flax should be inspected frequently for problem spots until the seed has cooled down. Flax has an airflow resistance very similar to Polish-type canola **(B. campestris).** Periodic checking is necessary to detect the development of hot spots.

As in other oilseeds and cereal grains, moisture migration will occur in stored flax. Even though the seed is binned with uniform moisture, high moisture spots can develop by moisture migration which happens in fall and early winter, as well as in spring.

STORAGE INSECTS

Stored flax is not troubled by storage insects as frequently as cereal grains. Insects that can be a problem in flax are: saw-toothed grain beetle, confused flour beetle, merchant grain beetle and red flour beetle. Research in Manitoba revealed that flax varieties vary in their susceptibility to the saw-toothed grain beetle. For example, Noralta showed less than 1% infestation, while Redwood 65 and Raja were 100% infested with the insect. The rusty grain beetle occurs occasionally in carlots of flax. It is suspected that this insect feeds on cereal admixtures in the flax.

The optimum temperature for rapid growth of insects is in the range of 30 to 35° C (86-95°F). Their activity is greatly retarded by temperatures below 18° C (64°F). If the grain is cool and dry, insects will generally not thrive. However, flax may be put into storage at an acceptable moisture content and temperature, but pockets of high moisture and temperature can develop later, encouraging insect activity.

TABLE 4

Characteristics of commonly grown flax varieties

Variety	Maturity	Height	Resistance to Lodging	Seed Size	Oil Content	Oil Quality	Reaction to Disease Rust	Wilt
Culbert	Medium	Medium	Good	Medium	Medium	High	Res.	Mod. Res.
Dufferin	Late	Med-tall	Fair-Good	Medium	High	Med-High	Res.	Mod. Res.
Linott	Early	Medium	Good	Small-Med	Medium	Med-High	Res.	Mod. Res.
McGregor	Late	Med-Tall	Very Good	Small	Medium	Med-High	Res.	Mod. Res.
Noralta	Early	Med-Tall	Fair-Good	Small	Low	Med-High	Susc.	Mod. Res.
NorLin	Medium	Medium	Good	Medium	Medium	Med-High	Res.	Mod. Res.
NorMan	Medium	Medium	Good	Medium	High	Low-Med	Res.	Mod. Res.
Vimy	Medium	Med-Tall	Fair	Med-Large	High	Med-High	Res.	Mod. Res.

TABLE 5

Yield (kg/ha*) of flax varieties in the three soil zones of the prairies - cooperative flax tests, 1983-1985

Variety	Soil Zone: Thin & Thin Black	Dark Brown & Brown	Gray and Gray Black	Average
Dufferin	1570	1450	1440	1500
Linott	1455	1380	1370	1410
McGregor	1570	1520	1475	1535
Noralta	1425	1445	1455	1440
NorLin	1590	1535	1275	1520
NorMan	1550	1495	1375	1500
Vimy	1585	1545	1385	1540

* 1 kg/ha = .892 lb/ac

TABLE 6

Fungicides for treatment of flaxseed

Active Ingredient*	Formulation
Carbathiin	Dust and Wettable Power
Carbathiin-thiram	Dust and Suspension
Maneb	Dust and Suspension
Mancozeb	Wettable Powder
Metiram	Dust and Suspension

*The fungicides may be sold under various commercial names

TABLE 8

Yield (kg/ha*) of flax varieties in five seeding dates at two locations - Morden and Portage La Praire, Manitoba, 1982 - 1984

Variety	Seeding Date: May 10	May 20	June 1	June 10	June 20
Culbert	1955	1970	1860	1670	1120
Dufferin	2160	2150	1930	1360	760
Linott	2090	2070	1910	1685	1265
McGregor	2225	2220	2025	1655	1145
Noralta	1990	1970	1915	1230	895
NorLin	2185	2205	2195	1610	1065
NorMan	2135	2155	1945	1445	995
Average	2130	2130	1985	1495	1020

* 1 kg/ha = .892 lb/ac